The Nature of Sound and Visual Image

Digital Image and Sound Processing

assoc. prof. dr. Kęstutis Jankauskas
kestutis.jankauskas@ktu.lt

KTU. Department of Multimedia Engineering

Today in the Slides

- **The Nature of Sound**
  - Physical Characteristics and Properties
  - Sound Wave Interaction
  - Importance of Time Factor
  - Sound Perception
- **The Nature of Visual Image**
  - Physical Characteristics and Properties
  - Image Perception

The Nature of Sound

- Sound is a mechanical wave of pressure and displacement propagating through gas, liquid, or solid mater
- Sound may be reflected, refracted, or absorbed in an acoustic medium
- Sound does not transmit through vacuum

[1, 2, 3, 4]

Physical Characteristics of an Acoustic Wave

- **Wavelength** and **Frequency** (related to Pitch)
- **Amplitude** (related to Loudness)
- Phase
- Propagation speed
- Attenuation

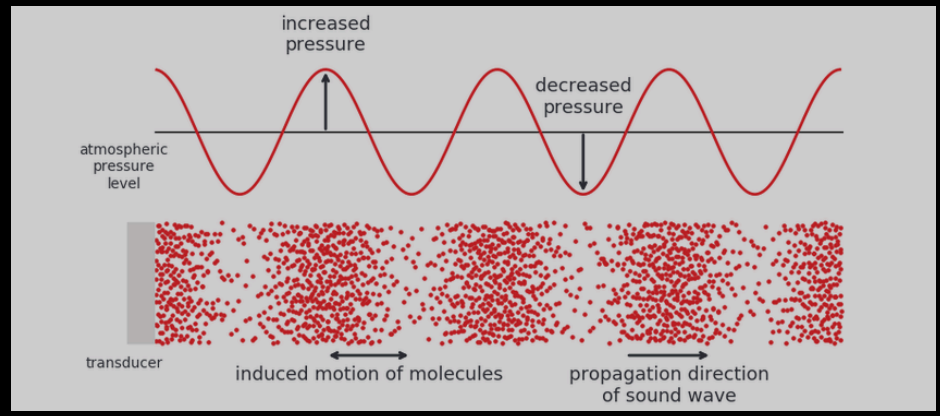
[5, 6, 7]

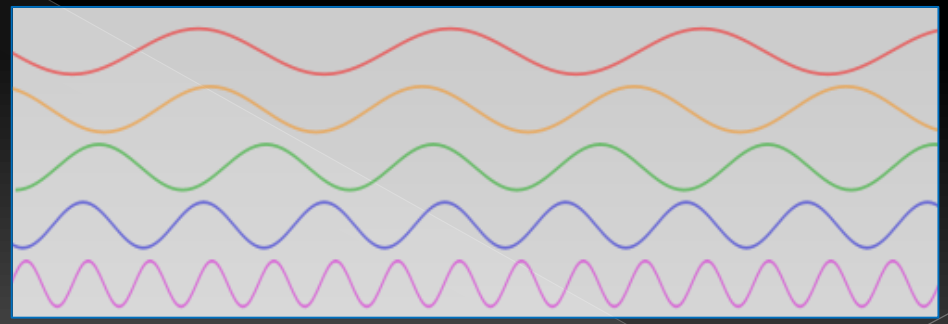
Wavelength and Frequency

$$E(t) = Asin(2\pi ft + \varphi)$$

$$f = \frac{v}{\lambda} \qquad f = \frac{1}{T} \qquad \lambda = Tv$$

A - amplitude
t - time
λ - wavelength
f - frequency
T - period
v - velocity
φ - phase





Amplitude-related Properties

- Sound **intensity** (loudness or volume)
- Sound with **higher amplitude** waves is interpreted as **louder** by a human ear
- Amplitude is **measured in decibels** (dB)
  - **Logarithmic** measurement scale, which indicates the intensity of pressure provided by sound waves
  - Ratio between a sound of harmful loudness and a barely audible sound is more than 10^{12} times
  - The upper bound is defined as 120 dB and the lower bound as 0 dB

[8]

Frequency-related Properties

- **Audible** sound **range** extends from **20 Hz** to **20 kHz**
- Low frequency sound – low pitch
- High frequency sound – high pitch
- Sound consists of waves with **many** different **frequencies**
  - Frequencies higher than fundamental frequency are called **overtones**
  - Frequencies equal to fundamental frequency multiplied by a whole number factor are called **harmonics**
  - A set of overtones gives an instrument a specific **timbre** (color)

[13]

Acoustic Medium-related Properties

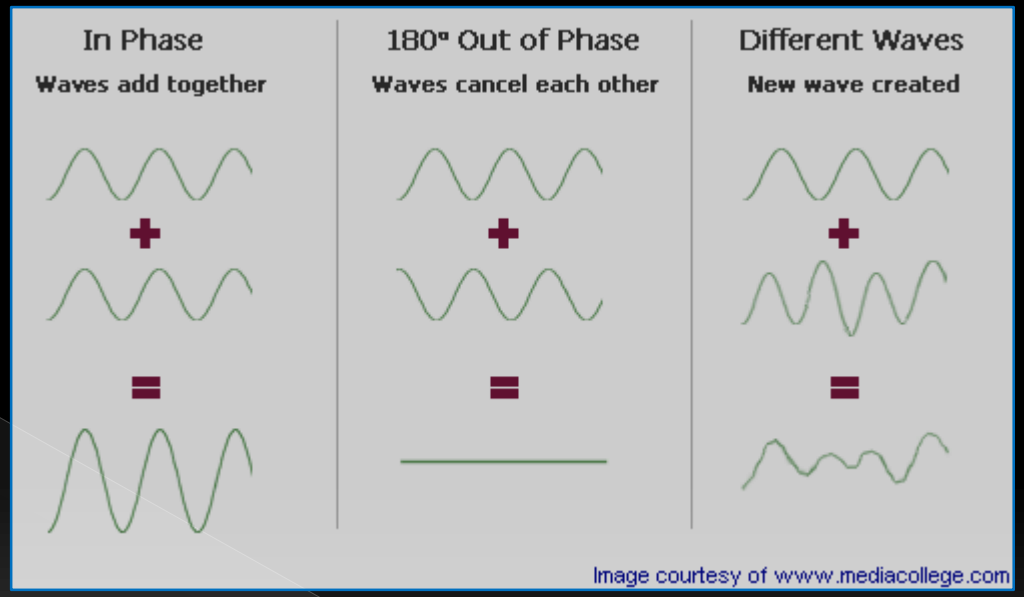
Sound propagation speed and attenuation depend on **physical properties** of an acoustic medium:

- **Density**
- **Pressure**
- **Viscosity**
- **Temperature**
- **Movement** of an **acoustic medium** itself

[9]

Sound Wave Interaction

- **Same frequency** and **phase** signals reinforce each other
- **Same frequency** and **opposite phase signals** cancel each other
- **Different frequency** and **phase** waves create a new waveform



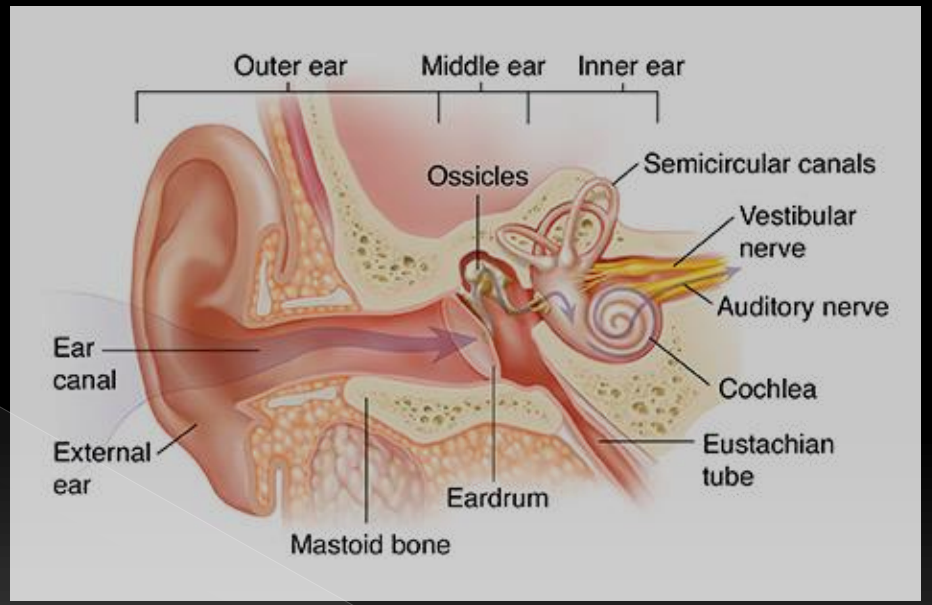
[10]

Importance of Time Factor

- **Time** is necessary to **create**, **transmit** through an acoustic medium, and **capture** any sound
- **All physical characteristics**, except amplitude and attenuation, **are** directly **related to time**
- Sound information is meaningful only in an arbitrary time span (it may be a very short period)

Sound Perception

- There are three zones in a human ear:
  - **Outer ear** (transition)
  - **Middle ear** (conversion to mechanical energy)
  - **Inner ear** (conversion to neural impulses)
- Brain ability to distinguish frequencies is limited



[11]

The Nature of Visual Image

- Image is a projection of light on an eye retina
- The ability of light to be reflected by objects allows us to perceive object shape, color, and a material that object is made from

[15]

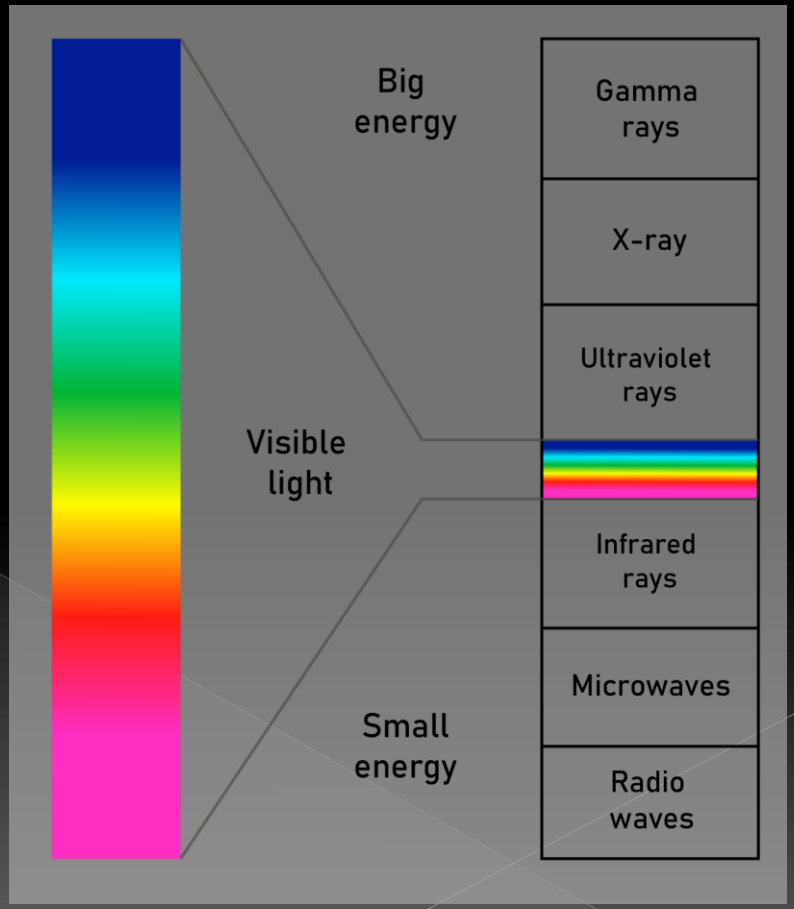
Physical Interpretation

- Light is an **electromagnetic radiation** of frequencies in a visible range
- Electromagnetic radiation can also be described in terms of a stream of **photons** which are massless particles each travelling with wavelike properties at the speed of light
- Important characteristics:
  - **Intensity** (wave amplitude)
  - **Color** (wave frequency)

[15, 21, 22]

Light Intensity and Color

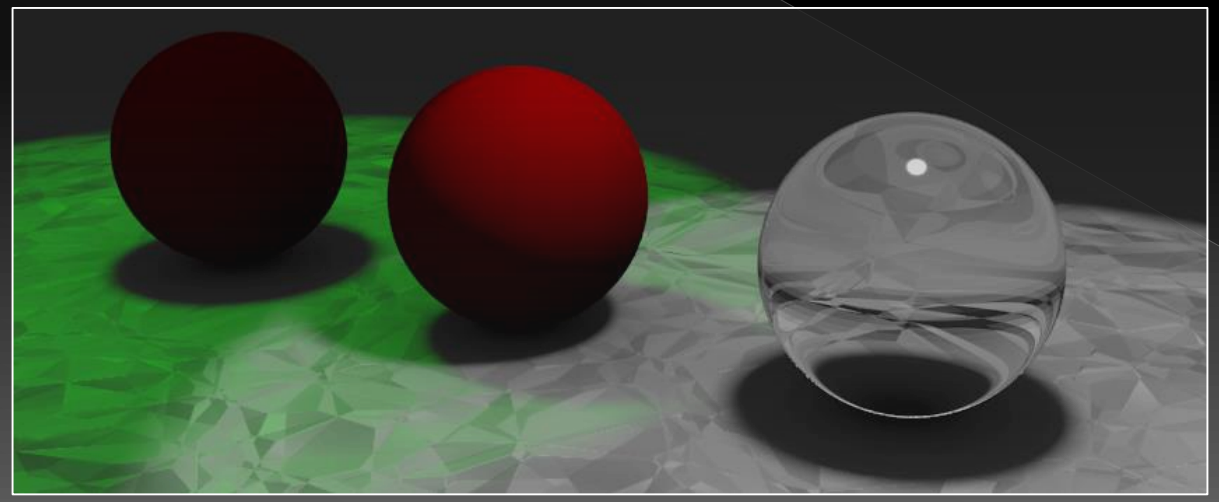
- The **brightness** of an image is related to the **intensity** of light
  - Objects appear to be colorless in **poor lighting**
- Light color depends on its **wavelength** (frequency)
- Visible light range is from 380 nm to 740 nm
  - Long waves appear as a red light
  - Short waves appear as a violet light
  - White light consists of all visible wavelengths
  - There is no black light



[16]

Object Optic Properties

- Optic material can affect light in three ways:
  - Light can be **reflected**, **absorbed**, and **refracted**
- Light of **different wavelengths** may react differently to the same material



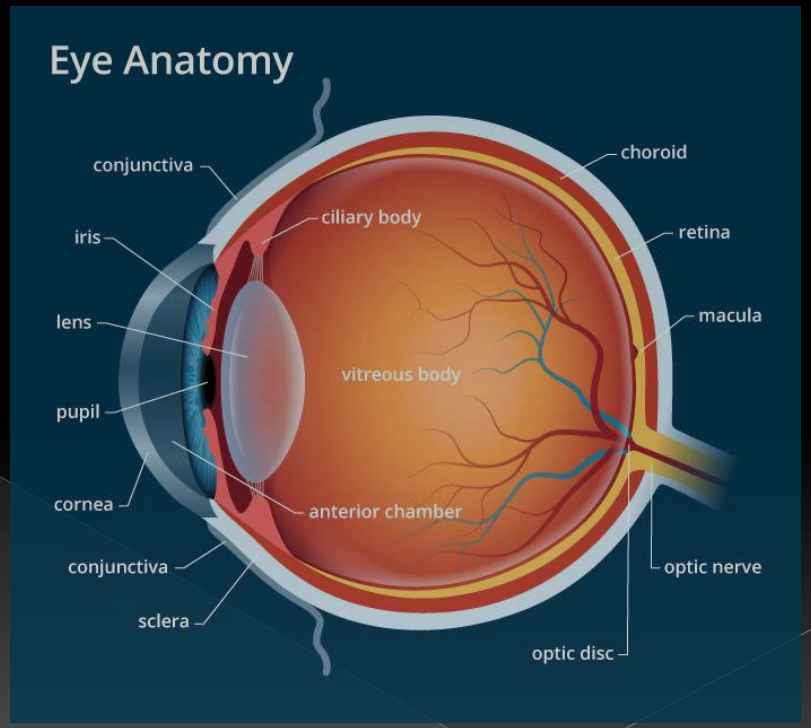
Speed of Light

- The speed of light equals **300 000 km/s** and is **constant** in a vacuum
- Speed is smaller in transparent materials
  - Speed itself is constant, but it takes time for a material to absorb and re-emit light particles

[15, 20]

Image Perception

- Image capturing process involves **eyes** & **brain**
- **Iris** balances the amount of light entering the eye
- **Lens** focuses the projection on a **retina**
- **Retina photoreceptors** convert visual information to neural impulses and send them to brain via the **optic nerve**
- Image information is processed in a specific brain area called **visual cortex**



[21, 22, 23]

Interesting Facts

- In music one octave distance between tones is equivalent to double fundamental frequency
- In music a chord consists of several notes; Furier transform allows to decompose a signal into separate frequencies and identify notes
- Dogs can hear ultrasound, but cannot hear frequencies below 40 Hz
- Some species of bats can hear sounds up to 200 kHz frequency, this compensates for their poor vision
- Under 20°C normal pressure conditions sound travels at speed of 340 m/s, it is 4.4 times faster in water (1500 m/s), and is even more fast in steel (5800 – 5960 m/s)
- The sound of thunder is produced by rapidly heated air surrounding lightning channel that expands faster than the speed of sound
- Signal-to-Noise Ratio (SNR) of 90 dB is inaudible for a human ear

[12, 13]

Interesting Facts

- Blinking removes dust from an eye surface, an eye is lubricated, an eyelid protects an eye from small particles floating in the air
- Human blinks every 2 – 10 seconds, an eye stays closed for 0.3 second (total 30 minutes per day)
- We cannot fully see 3D image with one eye closed, but brain can restore pieces of missing information from lens distortion, motion, and experience
- Animal eyes glow in the dark because of a reflective tissue in the back of the eye, which improves eyesight in bad lighting conditions
- An infant sees the world upside down, because of the optical system of the eye rotates the view 180°, later the brain learns how to rotate it back automatically
- One of twelve males is color blind

[19, 24]

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